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RESEARCH ARTICLE

REVISED Climate clubs: an experimental study of Nordhaus' proposal to mitigate climate change

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Abstract

Background

Climate change poses a global collective action challenge, requiring mechanisms that can sustain cooperation among nations and their citizens. Nordhaus proposed the concept of "climate clubs" as a voluntary institutional framework to overcome free-riding in international climate policy by linking participation to mutual benefits and sanctions. This study experimentally examines whether such clubs can promote and stabilize cooperation in heterogeneous groups.

Methods

We conducted controlled online experiments in which participants, representing countries with different endowments, decided whether to form voluntary coalitions that coordinated emissions reductions. Four treatments were compared, varying in club formation rules (unanimity versus majority) and in the presence or absence of sanctions for non-members. Participants' pledges, commitments, and contributions were tracked across repeated rounds to assess both cooperation levels and coalition stability.

Results

Climate clubs significantly increased and stabilized cooperation relative to the baseline public goods game. The unanimity rule fostered more robust coalitions by enhancing commitment, but it did not necessarily raise overall contribution levels. By contrast, sanctions

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for non-members strongly incentivized high-endowment participants to contribute more and to sustain their participation. Cooperation under sanctioning conditions remained high and less variable across rounds, indicating that enforcement mechanisms reinforced stability and resilience in collective action.

Conclusions

Our results show that Nordhaus' climate club framework can effectively promote enduring cooperation when supported by credible sanctions. While unanimity rules strengthen collective commitment, they are not required to achieve high cooperation levels. These findings suggest that climate clubs represent a promising institutional approach to achieving stable, inclusive, and sustained international cooperation in climate mitigation.

Plain Language Summary

Climate change is a global problem that requires countries to cooperate in reducing greenhouse gas emissions. However, such cooperation is difficult to maintain because every country benefits from others' efforts while trying to avoid its own costs—a situation known as "free riding." Economist William Nordhaus proposed the idea of "climate clubs," in which countries that join an agreement enjoy mutual benefits, while those who stay outside face trade penalties.

In this study, we used online experiments to see whether such climate clubs could really encourage cooperation. Participants played a game that mimicked countries with different levels of wealth deciding whether to join a coalition to cut emissions. We found that climate clubs help increase and stabilize cooperation. Sanctions for non-members were particularly effective, making wealthier participants contribute more. Requiring everyone to agree (unanimity) made clubs more stable but not necessarily more generous. These findings suggest that climate clubs—with fair and credible enforcement—could be a realistic way to support long-term cooperation in international climate policy.

Keywords
public goods game, climate clubs, experimental economics, human behaviour

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REVISED **Amendments from Version 1**

In this revised version, we have clarified and strengthened the manuscript in response to reviewers' comments. The title and author list are unchanged. In the abstract, we added the words "and their citizens" in the Background section to clarify that the cooperation problem concerns not only nations but also the individuals within them. In the Introduction, we expanded the discussion of recent literature and clarified the policy relevance of our study, especially regarding the effects of sanctions, and the limitations of the experimental design. No new tables were added. We also updated references and made minor textual corrections throughout to improve clarity and accuracy.

Any further responses from the reviewers can be found at the end of the article

Introduction

Climate is a global public good, and climate change represents perhaps the most difficult collective action problem in human history.[1] When such problems concern common pool resources like the atmosphere, they take the form of a "Tragedy of the Commons".[2] Climate change mitigation can be promoted through two broad mechanisms: by influencing social preferences—changing players' motivations and behaviors—or by creating institutions, i.e., modifying or introducing rules of the game. In this paper we focus on the latter, and specifically on Nordhaus' proposal of climate clubs voluntarily formed by countries,[3] an idea recently taken up by the G7 under the German presidency.[4,5]

Agreements on global public goods are difficult because individual countries have an incentive to defect, prioritizing national over global benefits. International environmental agreements have therefore been modeled as coalition-formation games.[6–8] In these models, the equilibrium number of signatories follows from internal and external stability conditions: no member should prefer leaving, and no outsider should have an incentive to join. Such conditions are necessary because treaties like the Kyoto Protocol and, to an even greater extent, the Paris Agreement cannot be externally enforced and must rely on incentives for compliance. Yet, these coalition models rarely generate strong mitigation efforts, particularly when free-riding temptations are high. Coordination is further hampered by wealth asymmetries[9,10] and by both strategic and scientific uncertainty.[11,12]

Tagliapietra and Wolff[13] argue that if the three largest economies—the United States, the European Union, and China—were to agree on a coordinated carbon border tax, such an initiative could trigger a global cascade of mitigation efforts. Their argument is grounded in the idea of minilateralism: progress on climate policy can emerge from a small coalition of major emitters whose joint actions reshape global incentives. By internalizing carbon costs at the borders, this coalition would make free-riding less profitable and thus attract additional countries over time. This reasoning aligns closely with the original spirit of Nordhaus' climate club proposal, yet it places greater emphasis on trade policy as a mechanism for diffusion.

In contrast, Vogt[14] highlights structural tensions that undermine such coalitions. His analysis shows that both wealthy and poorer countries may have incentives to leave a climate coalition, albeit for different reasons: rich countries tend to prefer withdrawal when they bear disproportionate abatement costs, whereas poorer ones gain by avoiding the disutility of inequality while still improving their absolute payoffs outside the coalition. Beyond these distributional motives, other strands of the literature have examined how cooperation dynamics depend on membership constraints. Dannenberg and Barrett[15] show that when group membership is partly involuntary and agents cannot freely choose their coalition, cooperation tends to emerge only slowly because learning and expectations adjust gradually. Heitzig and Kornek[16] extend this reasoning to dynamic environments, demonstrating that efficient coalitions can still arise if participants are sufficiently farsighted or if short-term coordination opportunities—such as post-linkage negotiation windows—are seized promptly. Together, these studies underscore how the timing, flexibility, and perceived fairness of coalition formation critically shape the prospects for sustained international cooperation.

Recently, Nordhaus has taken a new perspective on the issue at hand, incorporating the concept of repeated games. In his latest work,[17] the author expands upon the one-shot approach to encompass multiple periods, introducing a novel method that tackles "supportable policies" in a scenario involving multiperiod clubs. The study introduces a fresh aspect by considering the interaction between club effectiveness and rapid technological change, both of which are crucial to achieving the objectives of international climate policy. Nordhaus argues that trade sanctions alone will be too expensive to achieve significant abatement if not paired with rapid technological innovation, and that innovation by itself is still susceptible to countries free riding. However, the study suggests that the joint effect of those factors opens the door to achieving climate goals.

Karatayev *et al*.[18] have tackled the challenges associated with large-scale negotiations where committing to mitigation efforts can be expensive and uncommon. They propose a strategy that involves a well-timed policy shift from local to global legally binding agreements, which is shown to be more effective than relying solely on local, global, or both types of agreements concurrently. The rationale behind this approach is that local agreements help to build commitment and encourage mitigation in early-adopting groups, while global agreements are more effective in encouraging late-adopting groups to join the effort.

Several experimental studies have been conducted to investigate the formation of coalitions and the effectiveness of proposed institutions to mitigate climate change. McEvoy and Stranlund[19] found that the pay gap between coalition members and non-members negatively impacts coalition formation rates. Bosetti *et al*.[20] focused on effort coordination between coalition members and non-members in the context of a catastrophe and found that a sizable coalition of early investors in clean technology is more likely if benefits are appropriated by members. Schmidt and Ockenfels[21] found that negotiating a uniform common commitment is more effective than negotiating individual commitments or commitments tailored to specific situations. Finally, Dong *et al*.[22] found that financial incentives for developing countries lead to higher global contributions towards emissions reduction and effectively reduce emissions, even without binding enforcement. More broadly, recent contributions have emphasized the role of positive incentives and club-good benefits in facilitating climate cooperation within smaller coalitions. Hovi *et al.* (2017),[23] for example, show that sufficiently strong inducements and conditional commitments can foster the emergence and expansion of climate clubs. We recognize the importance of this incentive-based perspective. In contrast, our experimental design concentrates on isolating the institutional effect of sanctions within voluntary club formation.

A recent experiment by Casari and Tavoni (2024)[24] tested Nordhaus' climate club proposal under more realistic conditions, allowing sanctions to be costly for both sides and permitting counter-punishment. They found that clubs increased cooperation but not overall surplus, as mutual sanctions produced efficiency losses. Our study differs by focusing on the institutional rather than economic design of clubs. We examine how formation rules (unanimity versus majority) and credible sanctions influence cooperation and coalition stability in larger, heterogeneous groups. In this way, our work complements Casari and Tavoni's stress test by identifying the institutional conditions that make climate clubs viable.

As we have seen in our brief literature summary, the idea of climate clubs has been the subject of much theoretical research. This is also true for coalitions and similar institutions to fight climate change. However, the question naturally arises as to the real applicability of all those results.

There are two main reasons for this. First, the climate clubs proposal does not come with specific rules of the game to form the clubs. And it is possible that different rules about club formation yield different outcomes. In the theoretical literature, results are often negative (meaning that coalitions either do not form or are unstable). And many mechanisms proposed to deal with these issues have not been tested at all. Second, many possible game-forms associated with the climate clubs would have multiple equilibria. For example, if one thinks others are not going to join the club, and there are costs if not enough others join, then it is not optimal to pledge membership.

We therefore adopt an experimental approach to assess the viability of climate clubs as a mitigation tool. The question is timely, given the recently established G7 Climate Club,[5] whose current design relies primarily on coordination and incentives rather than sanctions. Our experimental approach points to several important insights:

- Climate clubs increase and stabilize cooperation for both participant types, i.e. highly- and lowly-endowed participants.
- The unanimity rule to form the climate club has little effect on the global contribution level.
- Highly-endowed participants contribute more when sanctions are present.

We thus find that, in this framework, Nordhaus' sanctioning scheme stabilizes cooperation levels and makes them resilient; it also provides strong incentives to form a large coalition of committed participants. Furthermore, the rule of unanimity is useful to establish robust coalitions and to avoid free-riding behaviors on commitments, but it is not required to achieve high levels of cooperation.

Recent policy developments suggest that existing climate clubs, such as the G7 Climate Club, rely primarily on coordination and incentive-based mechanisms, reflecting the political difficulty of implementing sanction-based

designs.[25–27] In this context, our approach does not aim to replicate current institutional arrangements, but rather to isolate and test a key mechanism of Nordhaus' original proposal—namely, the role of sanctions—in a controlled experimental setting. Our contribution is therefore not to propose an immediately implementable policy design, but to identify the behavioral and institutional effects of sanctions in climate club formation.

Experimental setup

The design of the laboratory experiment has been mainly inspired by Nordhaus (2015)[3] regarding the introduction of climate clubs within the framework of the climate change game, and by Kosfeld, Okada and Riedl (2009)[28] regarding the institution formation in ***N***-player games. It is important to summarize Nordhaus' proposal in order to see how our experimental setup reflects it.

The key idea behind the climate club is that members agree to undertake harmonized emissions reductions. For example, countries belonging to the club may commit to implement policies leading to a minimum domestic carbon emission price ($25 per ton of carbon dioxide in Nordhaus 2015,[3] the figure itself is not relevant for the discussion, but nowadays it is of course outdated and prices in the EU at the time of writing are approaching $100 per ton of carbon dioxide). Countries would be at liberty to choose their own specific mechanisms (such as carbon tax, cap-and-trade, or hybrid designs). Crucially, countries that are not members of the club are penalized. Nordhaus suggested that members could impose uniform percentage tariffs on the imports from non-members into the club territory. Our experimental design captures these features of Nordhaus' groundbreaking proposal.

In this manner, a strategic situation is created so that countries acting in their self-interest will join the club assuming very high levels of emissions reductions. The advantage of Nordhaus' system is that countries that do not comply can expect a punishment that is credible, because the members of the club benefit from it. In his paper, Nordhaus examined in detail the club and then considered an empirical model to show that it could actually work. His simulated model, with parameters taken from climate models, allows him to investigate the characteristics of stable climate clubs for different emission reduction targets. The main result he obtains from the model is that significant reductions in emissions can be obtained with clubs that are stable.

In accordance with this proposed institution, in our experiment we consider a group of ***N*** subjects playing together for an iterated sequence of rounds. At the beginning of each round, all participants make public announcements, i.e. pledges, regarding their will of taking part in a climate club. Subsequently, all participants decide if they want to ratify their participation within the coalition based on the number of other willing participants. In one treatment, the climate club is formed if and only if all pledging participants ratify their participation (unanimity rule), that is, a unanimous agreement must be achieved.

At the end of the round, all participants within the club costly abate their emissions and benefit from taxation on non-participants. We contrast the behavior observed in the climate clubs treatment against three baseline treatments. The simplest one did not consider climate clubs at all, that is, being a standard public goods game having the same multiplication factor. The second one included climate clubs but without having taxation on non-participants and without the unanimity rule to form the club. The third one included the unanimity rule but not taxation.

Considering the four experimental treatments, 195 subjects completed the experiment (average earnings = 12.96 EUR). Participants play 15 rounds in the same group of 6 members. Each group included two A-type participants, who were endowed with 20 points and were earning a fourth of the public good, and four B-type participants, who were endowed with 10 points and were earning an eighth of the public good. Each round included four stages:

1. **Pledging stage**: Subjects pledge their intention to join the coalition, but the pledge is not binding; this stage was not included in the standard public goods game treatment; This pledge decision will remain in their history of pledge decisions over the entire experiment, and participants have the history of pledge decisions of group mates available during the entire experiment. The same will occur with the rest of the decisions participants have to make in a round;

2. **Commitment stage**: Played only by participants who pledged to joining the club in the previous stage, while the rest of the participants simply skip this stage; subjects can confirm their positive pledge; this stage was not included in the standard public goods game treatment;

3. **Contribution stage**: If the coalition is formed, members of the coalition contribute with their entire round endowment while subjects who are not in the coalition freely contribute to the public good; if the coalition is not formed, each participant freely contributes;

4. **Payoff stage**: Subjects earn their round payoff; the total amount of points collected in the public good is multiplied by a multiplication factor of three and then distributed to all group members proportionally to their participant type; if a coalition is formed, benefits and sanctions are implemented (only for treatment T4).

We ran four different treatments. In treatment T1, there was only the contribution stage, i.e., it was a (heterogeneous) public goods game. Treatment T2 allowed clubs to be formed even if some of the members who initially pledged to join withdrew their pledge, whereas in treatment T3 clubs were only formed by unanimous ratification of all pledges. Both in T2 and T3 there were benefits to club members but no punishment to non-members. Treatment T4 introduced the punishment to non-members and at the same time it kept the unanimity rule. This last treatment was the one that more closely reflected the spirit of Nordhaus' proposal, so we will refer to it as the climate club treatment. The experimental setup including its four stages and for the T4 treatment is depicted in Figure 1. The English translation of the experimental instructions is provided in the supplementary information, see Section 1.

Results

The findings of our study are summarized in Figure 2, which reports the average weighted pledges (panel a) and commitment ratios (panel b) by treatment and participant type. The baseline treatment (T1) serves as a control and does not include these stages. When considering the total possible positive pledges as eight—derived from four *B-type* participants (weight = 1) and two *A-type* participants (weight = 2)—the average number of pledges remains around six or seven. This indicates that nearly all group members pledge positively, with no significant treatment effects at the global level (Mann–Whitney (MW) test; group and individual levels, $p > 0.05$). An exception arises when comparing T3 and T4 at the individual level (MW test; $W = 999$, $p = 0.020$), where a slightly higher preference for positive pledges is observed when sanctions are introduced. A closer look at participant types reveals a statistically significant difference within T3. In this treatment, *A-type* participants pledge positively less often than *B-type* participants (MW test, individual level; $W = 230$, $p = 0.036$*). A plausible interpretation is that, under the unanimity rule required for club formation, *A-type* participants may feel less pressure to join, anticipating that others will secure club formation without their own commitment. This pattern, however, disappears in T4, where sanctions and corresponding benefits are introduced—underscoring the importance of coupling unanimity rules with enforcement mechanisms.

Turning to the commitment stage (Figure 2b), participants generally ratify their pledges more frequently when a unanimity rule applies. This occurs consistently across T3 and T4 (MW tests — group level: T2–T3, $W = 8$, $p = 0.021$*; T2–T4, $W = 8$, $p = 0.006$**; T3–T4, $W = 25$, $p = 0.536$; individual level: T2–T3, $W = 546.5$, $p = 0.002$**; T2–T4, $W = 893$, $p < 0.001$***; T3–T4, $W = 1162.5$, $p = 0.240$). This evidence confirms that the unanimity

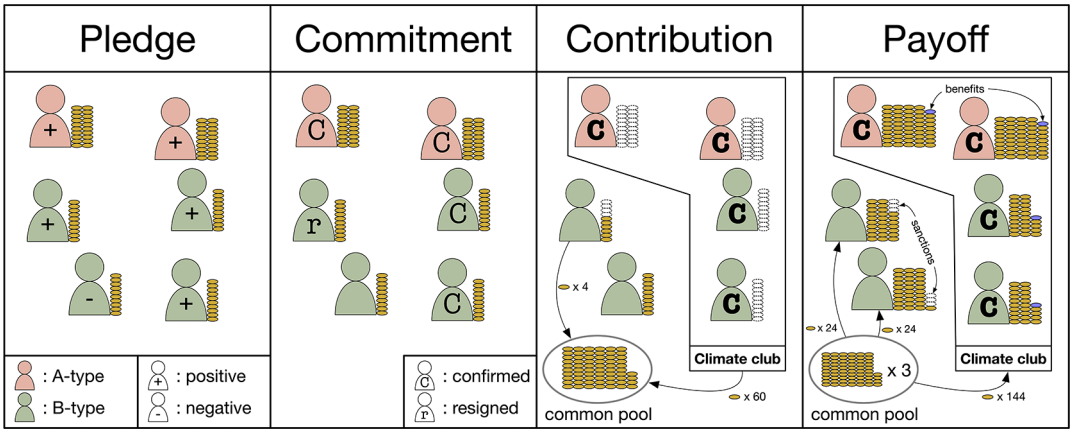


Figure 1. The experimental design comprises up to three active stages and a payoff stage per round. The six group participants are segmented into two A-type and four B-type players, where each A-type player carries the equivalent weight and endowment of two B-type players. In the baseline (T1), only contribution and payoff stages are present. The pledge stage includes participants' intent to join a climate club, ratified in the commitment stage. Climate clubs form according to treatment scenarios without (T2) or with (T3) unanimity. The payoff scheme adjusts with the introduction of sanctions and benefits (T4).

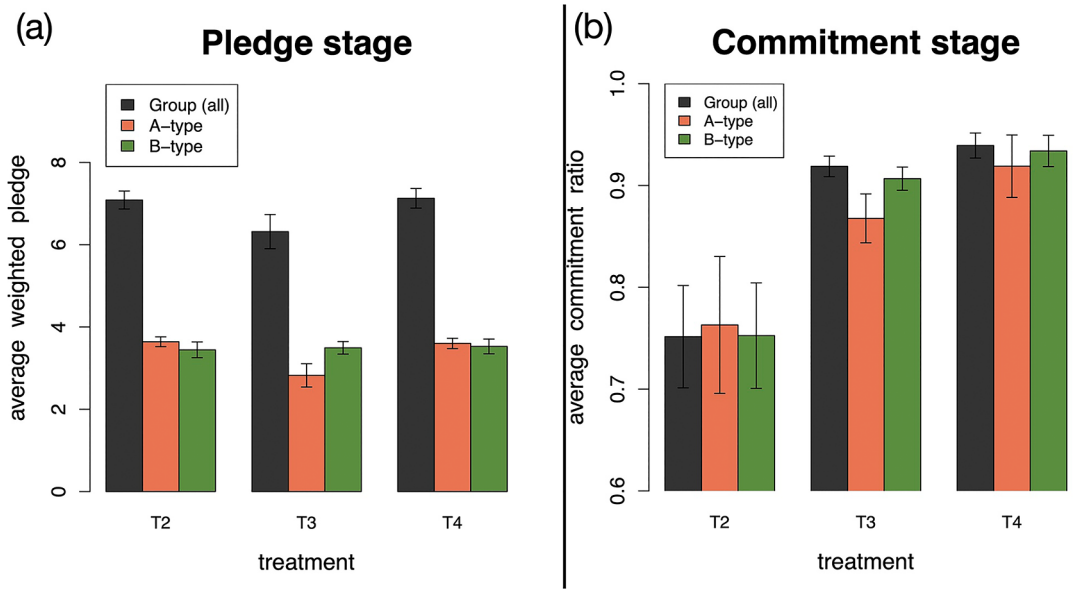


Figure 2. Average weighted pledge (a) and commitment ratio (b) by participant type and treatment.

rule fosters stronger commitment from the initial pledging stage. The earlier difference between participant types persists at this stage as well: in T3, *A-type* participants again ratify less frequently than *B-type* participants (Wilcoxon signed-rank test; $W = 233$, $p = 0.023$*). By contrast, when sanctions are implemented in T4, *A-type* participants' commitment rates rise to match those of *B-type* participants (Wilcoxon signed-rank test; $W = 493.5$, $p = 0.422$), further confirming the effectiveness of sanctions in sustaining engagement and compliance.

Figure 3 reports the normalized contributions to the public good (PGG) by treatment, round, and participant type. Contributions are normalized with respect to the total endowment per group (80 points), participant type (20 points for *A-type* and 10 points for *B-type* participants), and treatment. Overall, contributions to the common pool remain consistently high across all treatments. Although a decline in contributions is observed in T1, T2, and T3, this decay is notably less pronounced than in standard public goods game experiments. Formal tests are reported in the supplementary information (see Section 2.3), where we estimate the round trend both via OLS and a robustness specification (fixed effects by group and participant with two-way clustered standard errors). Both analyses show a significant negative slope only in T2 and T3, while T1 and T4 are not significant; even in T2–T3 the magnitudes are modest, consistent with a decay that is less pronounced than in standard public-goods experiments. The sustained cooperation can be attributed to the repeated interaction within fixed groups, which promotes direct reciprocity, as well as to the informational transparency of the design. Participants continuously observed the pledges, commitments, and contributions of all group members, with a five-round memory window. Such transparency likely fostered reputational incentives, as high contributions signaled reliability and commitment to collective goals. An interesting oscillatory pattern emerges in T3, corresponding to rounds in which climate clubs failed to form and contributions subsequently dropped. Despite similar average contributions in T2 and T3, behavior diverges by type. In the supplementary information (see Section 2.3), we find a significant A–B gap in both treatments: in T2, A-types contribute more than B-types; in T3, the pattern reverses. A pooled fixed-effects model confirms a strong and negative A–B gap only in T3, while the T2 gap attenuates and is not significant,

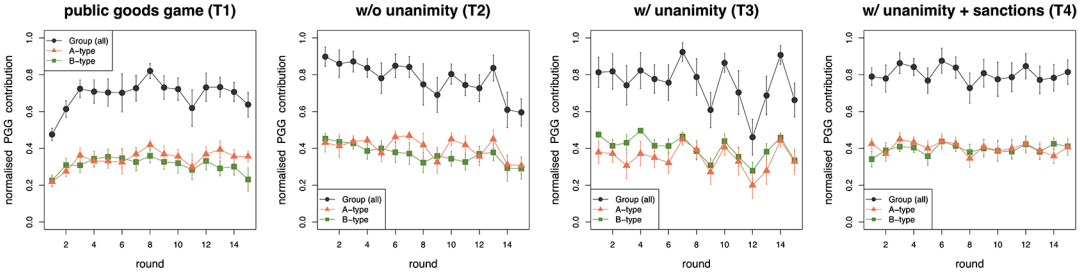


Figure 3. Normalised contribution by participant type, round and treatment.

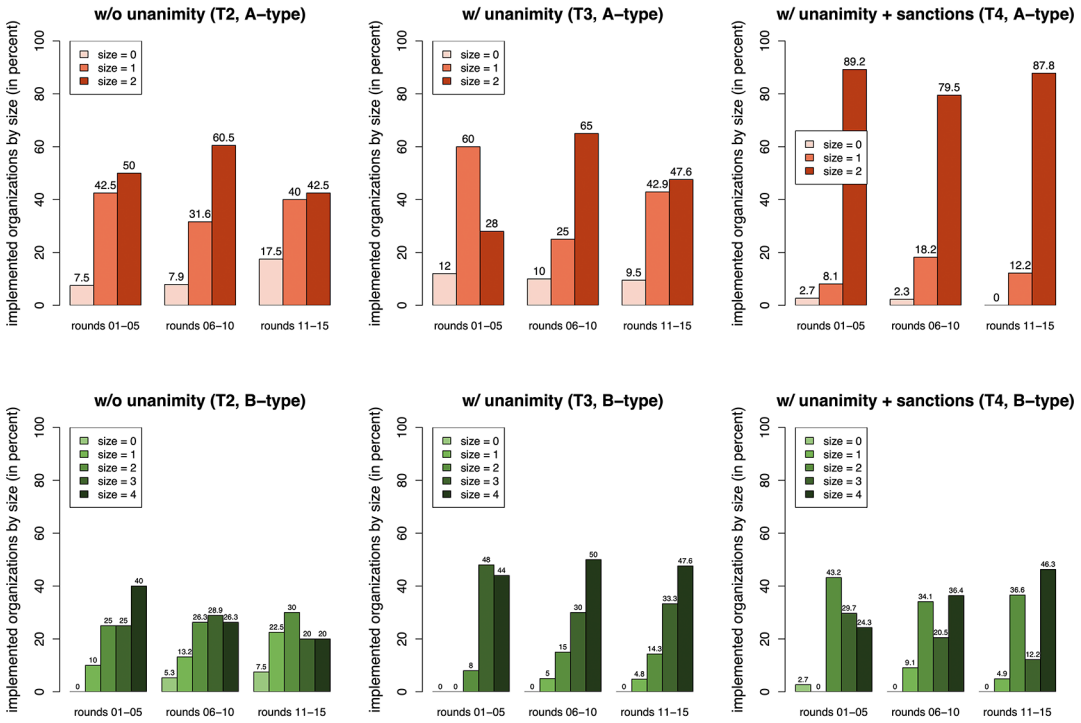


Figure 4. Climate club composition by participant type, round number and treatment.

indicating that part of the T2 difference is absorbed by persistent group heterogeneity. Notably, the unanimity rule in T3 appears to motivate B-type participants to contribute more, whereas A-types contribute relatively more under the non-unanimity setup T2. Finally, in the climate-club treatment (T4), contributions increased relative to all other treatments. Formal tests in the supplementary information (see Section 2.3) show that all T4–other differences are statistically significant. The stability analysis further indicates that behavior is more stable in T1 (albeit at much lower contribution levels) and in T4 (at higher levels) than in T2–T3. The presence of sanctions not only raised average contribution levels but also reduced their variability across rounds, indicating that sanctions stabilized cooperative behavior over time.

Finally, Figure 4 illustrates the composition of climate clubs by participant type, round number, and treatment. This analysis sheds light on the evolution of group dynamics and potential learning effects over time. Overall, behavioral patterns appear similar across treatments during both the initial and final rounds, suggesting a convergence of strategies as the game progresses. In T2, the typical climate club displays relatively homogeneous composition, usually including at least one *A-type* participant and about two *B-type* participants. This pattern persists in T3 for *A-type* participants, while the average number of *B-type* members within the club increases significantly (Welch t-test group level: T3–T2, $t = 2.225$, $df = 219.95$, $p = 0.027$*). By contrast, T4 exhibits a distinct and stable pattern: both *A-type* participants almost always join the club—approximately 90% of the time from the earliest rounds—while one or two *B-type* participants are often left outside. This configuration indicates that sanctions encourage stronger and earlier engagement among high-endowment players, reinforcing the role of enforcement mechanisms in sustaining cohesive coalitions.

In summary, our results indicate that Nordhaus' sanctioning scheme effectively stabilized and reinforced cooperative behavior. It created strong incentives for participants to form large and highly committed clubs, maintaining cooperation even under potentially destabilizing conditions. Sanctions had a particularly pronounced effect on wealthier participants, who faced greater potential losses when poorer members coordinated to form clubs that excluded them. This suggests that, in principle, climate clubs could serve as a mechanism through which less affluent countries exert leverage on richer ones—though the economic asymmetries in the real world are far greater than in our stylized experimental setting, so this interpretation must be made with caution. Pledges also played a crucial role in sustaining cooperation. Many participants appeared to adhere to their initial declarations even in the absence of explicit enforcement, indicating that voluntary commitments can exert genuine behavioral influence. Finally, the unanimity rule enhanced the robustness of the clubs. When club formation required unanimous agreement, pledges were almost always honored, and coalitions proved more stable. Nonetheless, similarly high levels of cooperation were achievable without unanimity, suggesting that while the rule strengthens collective commitment, it is not essential for achieving it.

Discussion

The central message emerging from our experiment is that Nordhaus' sanctioning scheme stabilizes cooperation and makes it resilient to potential breakdowns. Sanctions not only strengthen commitment within groups but also create strong incentives to form large and cohesive clubs of highly engaged participants. This effect is especially pronounced among highly endowed, or wealthier, participants, who respond more strongly to the presence of credible punishment mechanisms. The unanimity rule, although not indispensable for achieving high levels of cooperation, contributes to the robustness and stability of clubs by ensuring that commitments are more likely to be honored. Furthermore, pledges themselves play a pivotal role in sustaining cooperation: participants tend to respect their initial declarations even without external enforcement, suggesting that preliminary discussions and voluntary commitments can act as effective coordination devices in collective action contexts.

Our findings contrast with those of Casari and Tavoni,[24] who focus on the inefficiencies that arise when sanctioning and counter-punishment entail significant costs. In their framework, trade sanctions and retaliation dampen the overall effectiveness of climate clubs, reducing both cooperation and aggregate welfare. By contrast, our results indicate that when sanctions are credible, well-calibrated, and embedded within transparent institutional procedures, cooperation not only increases but also becomes more stable. This difference highlights that the institutional architecture of climate clubs —the rules governing membership, decision-making, and enforcement—may be as decisive for their success as their economic design. In other words, the durability of climate cooperation depends not only on the magnitude of incentives but also on the way in which collective commitments are structured and communicated.

Naturally, our work comes with limitations. As in most laboratory studies, the participant pool—university students—cannot fully replicate the preferences, strategic reasoning, or political constraints of actual policymakers. The debate on the external validity of laboratory experiments in economics remains open. Levitt and List[29] strongly argue that laboratory findings may not translate easily to real-world behavior, while Camerer[30] counters that experimental evidence remains essential for understanding the mechanisms underlying cooperation. Regardless of this ongoing discussion, further research using different samples, cultural contexts, and more naturalistic or field-based settings would be valuable to test the robustness of our conclusions. Alternative methodological approaches, such as large-scale simulations or agent-based models calibrated to real data, could also complement experimental evidence and help capture general equilibrium effects that are beyond the scope of controlled laboratory environments.

Another limitation concerns the scope of our experimental design, which does not include the possibility of retaliation by countries that remain outside the club. Retaliation could reduce the attractiveness of joining a climate club by offsetting some of the benefits of membership. However, such effects would likely be limited if a sufficiently large fraction of countries participate, as our data suggest. In this case, the collective weight of the club could deter effective retaliation, preserving the stability of the coalition.

In addition, we have not explored the full range of mechanisms that could facilitate or hinder group formation. For instance, we observed that anonymity can help sustain cooperation by reducing reputational pressures that might otherwise induce short-term opportunism. Nevertheless, future work could test the role of intermediate decision rules, such as supermajority requirements, to assess whether they balance inclusivity and efficiency more effectively than unanimity. Likewise, while our findings confirm the usefulness of sanctions, it would be valuable to systematically vary their magnitude to identify the optimal level of deterrence that maximizes cooperation without imposing excessive costs. Finally, the small group size adopted here—an unavoidable constraint to ensure statistical control—limits the direct comparability with real-world institutions. In practice, climate clubs may need to encompass dozens of countries. Yet, as Nordhaus[3,17] and Tagliapietra and Wolff[13] suggest, a coalition of only a few major economies could already generate substantial global leverage by setting de facto international standards.

Lastly, as mentioned in the introduction, institutional design is only one of the two main levers to address climate change. The other concerns the evolution of social preferences—namely, the willingness of individuals and nations to act prosocially even when immediate self-interest would dictate otherwise. These two mechanisms are likely to be mutually reinforcing. Well-designed institutions, such as climate clubs, can harness and amplify intrinsic motivations, while strong social norms can, in turn, make institutions more legitimate and self-enforcing. Encouraging moral commitment and a sense of shared responsibility becomes easier when cooperative behavior is already visible and rewarded. In this sense, effective climate clubs may represent not only a policy innovation but also a vehicle for fostering enlightened self-interest on a global scale.

Materials and methods

We programmed the online experiment using oTree (v1.3) and recruited participants through the IBSEN platform. Before each session, participants were randomly assigned to one of the four treatments. Three experimental sessions were conducted in November 2020, involving a total of 195 active participants (out of 210 recruited) who completed the entire experiment. Experimental points were converted into real money at an exchange rate of 50 points = 1 EUR. On average, participants earned 12.96 EUR (≈15 USD), including a 2 EUR participation fee. At the beginning of each session, participants had up to ten minutes to read detailed instructions about the task. Those who were absent at the start or who missed more than two decisions during the experiment were excluded from payment. In such cases, automatic decisions were implemented, randomly sampled from other active participants within the same session. Each session lasted approximately 50 minutes. The supplementary information provides the full experimental instructions and representative screenshots, see Section 1.

This study was conducted in accordance with the principles of the Declaration of Helsinki. The experimental protocol was reviewed and approved by the Comité de Ética en la Investigación (Committee of Ethics in Research) of Universidad Carlos III de Madrid, under approval reference CEI2019_007 (approval date: 29 April 2019). The experiment involved fully anonymous participation and collected no personal or sensitive data. All participants provided written informed consent before taking part in the experiment, through an electronic confirmation screen implemented in the oTree interface. Participants were informed about the purpose of the study, the anonymity of their responses, and their right to withdraw at any time without penalty. Supplementary information (Extended Data) — including the English translation of the full experimental instructions, screenshots of the oTree interface, and an example consent form — are available in the Zenodo repository linked under Data Availability.

Use of AI tools

In accordance with the F1000 AI Policy, the authors disclose that ChatGPT (GPT-5, OpenAI, November 2025) was used to assist in improving the clarity and presentation of the manuscript and in drafting R code for data analysis. The use of this tool was limited to language refinement and code preparation under the direct supervision of the authors. All conceptualization, data analysis, interpretation of results, and conclusions are entirely the work of the authors.

Data availability

All data supporting this study are openly available in Zenodo[31] at: https://doi.org/10.5281/zenodo.17610157

The repository includes:

– The full experimental dataset and variable definitions;

– The Extended Data, including:

- English translations of the experimental instructions,
- Representative screenshots of the oTree interface used during the experiment,
- Example consent form used in participant recruitment.

All materials are shared under the Creative Commons Zero (CC BY 4.0 or CC0 1.0 Public Domain Dedication) license, as specified in the Zenodo record. Readers who require further clarification about the dataset or analysis may contact the corresponding author. No new software was developed as part of this study.

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Open Peer Review

Current Peer Review Status: ? ✓

Version 2

Reviewer Report 19 May 2026

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✓

Florentine Koppenburg
Technical University of Munich, Munich, Germany

I appreciate the authors revising the article in accordance with the comments they received. The revised paper looks much improved and has clearer findings to offer.
One final comment is that the sentence "We therefore adopt an experimental approach to assess the viability of climate clubs as a mitigation tool." should be amended to include the distinction between sanctions-based and incentives-based economic climate clubs rather than claiming to test the viability of the entirety of climate clubs. I also don't see the the authors actually testing the political viability, but rather then impact of institutional design questions. The paper would profit from stating that clearly in the same sentence.

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Political Science, International Climate Politics, Climate Clubs

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Version 1

Reviewer Report 10 February 2026

https://doi.org/10.21956/openreseurope.19049.r68941

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Florentine Koppenburg
Technical University of Munich, Munich, Germany

I recommend major revisions for three reasons, each of which will be explained in more detail below:
1) The paper does not engage with recent club literature.
2) The paper does not consider recent political developments in real-life climate clubs.
3) The authors inadequately explain and justify the choices involved in designing the experiment.

First, the paper does not engage with recent club literature that highlights the importance of incentives over sanctions. The sanctions vs. incentives debate has been present since at least 2017 (see Hovi et al.'s 2017 paper on 'The Club Approach: A Gateway to Effective Climate Co-operation?'). Not considering the findings from this longstanding debate for the experimental design constitutes a regrettable omission the authors should address.
Concretely, on page 4, the authors write: "*Dong et al. found that financial incentives for developing countries lead to higher global contributions towards emissions reduction and effectively reduce emissions, even without binding enforcement."* The authors even follow this up with: *"These experimental results highlight the importance of carefully designed experiments to shed light on the applicability of proposed institutions for mitigating climate change."* By simply stating the importance of incentives without considering them in their design, or explaining why they can or should be omitted, they violate the very care they stress should be employed in designing experiments. In doing so, the experimental design is in line with the club literature from a decade ago, but not with the more recent scholarship. Given the focus on institutional design, this presents a severe shortcoming.
Second, the paper does not consider recent political developments in real-life climate clubs, including the G7 Climate Club referenced in the paper. On page 5, the authors write: "*We therefore adopt an experimental approach to assess the viability of climate clubs as a mitigation tool. The question is timely, given current discussions on establishing a G7 climate club."* The G7 Climate Club has long been established. While early discussions considered sanctions, this approach proved politically difficult and the institutional design ultimately adopted by the G7 Climate Club employs incentives rather than sanctions.
This connects back to the point about not considering recent club literature. It has been pointed out as early as 2016 by Keohane & Victor in their paper on 'Cooperation and discord in global climate policy' that climate clubs are difficult to implement. This point was also made in Falkner et al.'s 2022 paper on 'Climate clubs: politically feasible and desirable?' They delineate three different types of climate clubs and identify the economic climate club —the type covered in this paper— as the politically most difficult to create. That explains why the other two types of climate clubs exist, but economic climate clubs have yet to materialize in political practice. A recent paper I wrote (2026, 'Open Coalition to make climate clubs politically feasible') assessed a case under discussion, namely the 'Open Coalition on Compliance Carbon Markets' that came out of COP30 in Belém in 2025. Similar to the G7 Climate Club, the Open Coalition considers incentives rather than sanctions to attract new members. Considering this and the backlash faced by the EU CBAM as the only existing de-facto economic climate club, choosing an experimental design that represents political realities is paramount to identifying a mechanism "that can sustain cooperation among nations" as the authors state their aim in the abstract.
Third, the authors inadequately explain and justify the choices involved in designing the experiment. To begin with, why did the authors choose 210 subjects? Why not include incentives in the experimental design? The first stage of the experiment consists of subjects pledging their

intention to join the coalition. Where does the assumption come from that most are willing to cooperate? If most states were willing to cooperate, the Paris Agreement would be a resounding success and clubs may not even be needed. Given the political hurdles a club with sanctions faces and major emitters being reluctant to engage in global climate cooperation, assuming a willingness to participate seems rather far-fetched and unlikely to yield results that can be implemented in practice.

Is the work clearly and accurately presented and does it engage with the current literature?
No

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

Are all the source data and materials underlying the results available?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Political Science, International Climate Politics, Climate Clubs

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 24 Mar 2026

Alberto Antonioni

I recommend major revisions for three reasons, each of which will be explained in more detail below:
1) The paper does not engage with recent club literature.
2) The paper does not consider recent political developments in real-life climate clubs.
3) The authors inadequately explain and justify the choices involved in designing the experiment.

Below, we respond point by point to the three main concerns raised, and clarify how we position our contribution within the recent literature and current policy developments on climate clubs.

First, the paper does not engage with recent club literature that highlights the importance of incentives over sanctions. The sanctions vs. incentives debate has been present since at least 2017 (see Hovi et al.'s 2017 paper on 'The Club Approach: A Gateway to Effective Climate Co-operation?'). Not considering the findings from this longstanding debate for the experimental design constitutes a regrettable omission the authors should address. Concretely, on page 4, the authors write: "Dong et al. found that financial incentives for developing countries lead to higher global contributions towards emissions reduction and effectively reduce emissions, even without binding enforcement." The authors even follow this up with: "These experimental results highlight the importance of carefully designed experiments to shed light on the applicability of proposed institutions for mitigating climate change." By simply stating the importance of incentives without considering them in their design, or explaining why they can or should be omitted, they violate the very care they stress should be employed in designing experiments. In doing so, the experimental design is in line with the club literature from a decade ago, but not with the more recent scholarship. Given the focus on institutional design, this presents a severe shortcoming. We fully acknowledge the importance of the incentives-versus-sanctions debate in the climate club literature, and this is precisely why we refer to incentive-based approaches in the Introduction. We agree that the discussion initiated by Hovi et al. (2017) and further developed in subsequent contributions is highly relevant. In the revised manuscript, we have now explicitly incorporated this reference in the literature review section, where we review alternative institutional logics. Our experimental design, however, deliberately focuses on the punishment component of Nordhaus' original proposal. The aim of the paper is not to compare sanctions and incentives, but to isolate and study the institutional effect of sanctioning within voluntary climate clubs. To the best of our knowledge, no previous experimental study has examined the pure effect of sanctions—separately from broader incentive packages—on coalition formation and stability in heterogeneous groups. We believe that identifying this isolated effect is valuable in itself, as it clarifies the specific mechanism through which enforcement may stabilize cooperation. We agree that incorporating explicit positive incentives into the experimental design would be an interesting and important extension. However, doing so would substantially alter the institutional structure under study and move beyond the scope of the present contribution. We therefore see such a design as a promising direction for future work, building on the framework developed here. Second, the paper does not consider recent political developments in real-life climate clubs, including the G7 Climate Club referenced in the paper. On page 5, the authors write: "We therefore adopt an experimental approach to assess the viability of climate clubs as a mitigation tool. The question is timely, given current discussions on establishing a G7 climate
club." The G7 Climate Club has long been established. While early discussions considered sanctions, this approach proved politically difficult and the institutional design ultimately adopted by the G7 Climate Club employs incentives rather than sanctions. This connects back to the point about not considering recent club literature. It has been pointed out as early as 2016 by Keohane & Victor in their paper on 'Cooperation and discord in global climate policy' that climate clubs are difficult to implement. This point was also made in Falkner et al.'s 2022 paper on 'Climate clubs: politically feasible and desirable?' They delineate three different types of climate clubs and identify the economic climate club —the type covered in this paper— as the politically most difficult to create. That explains why the

other two types of climate clubs exist, but economic climate clubs have yet to materialize in political practice. A recent paper I wrote (2026, 'Open Coalition to make climate clubs politically feasible') assessed a case under discussion, namely the 'Open Coalition on Compliance Carbon Markets' that came out of COP30 in Belém in 2025. Similar to the G7 Climate Club, the Open Coalition considers incentives rather than sanctions to attract new members. Considering this and the backlash faced by the EU CBAM as the only existing de-facto economic climate club, choosing an experimental design that represents political realities is paramount to identifying a mechanism "that can sustain cooperation among nations" as the authors state their aim in the abstract. We thank the reviewer for this comment. We agree that the policy landscape has evolved since the initial discussions around climate clubs, and we have revised the manuscript to reflect that the G7 Climate Club has now been established and that current implementations tend to rely more on incentives than on sanctions. Our aim in this paper, however, is not to reproduce existing policy designs, but to test a specific institutional mechanism originally proposed by Nordhaus, namely the role of sanctions in sustaining cooperation. While recent contributions have highlighted the political difficulty of implementing sanction-based climate clubs, this does not make the underlying mechanism uninformative. On the contrary, isolating its effect in a controlled setting allows us to assess whether and how sanctions can stabilize cooperation, independently of current feasibility constraints. We have clarified this point in the revised manuscript by explicitly distinguishing between (i) positive, incentive-based clubs that are currently emerging in practice, and (ii) economic climate clubs with enforcement mechanisms, which remain more challenging to implement. Our contribution is intended to speak to the latter, by providing experimental evidence on one of its key components. We also acknowledge that incorporating more realistic policy features—such as incentive-based accession mechanisms—would be a natural extension of this work and an important direction for future research. Third, the authors inadequately explain and justify the choices involved in designing the experiment. To begin with, why did the authors choose 210 subjects? Why not include incentives in the experimental design? The first stage of the experiment consists of subjects pledging their intention to join the coalition. Where does the assumption come from that most are willing to cooperate? If most states were willing to cooperate, the Paris Agreement would be a resounding success and clubs may not even be needed. Given the political hurdles a club with sanctions faces and major emitters being reluctant to engage in global climate cooperation, assuming a willingness to participate seems rather far-fetched and unlikely to yield results that can be implemented in practice. First, the sample size (210 active subjects) was determined to ensure a sufficient number of independent groups across treatments, allowing for meaningful statistical comparisons. This choice follows standard practice in experimental economics, where the unit of observation is the group rather than the individual (for a total of 35 independent groups). Preliminary power calculations indicated that this sample size would be sufficient to detect statistically meaningful effects. All results are reported based on the available data. While a larger number of observations would have increased statistical power, the sample size was ultimately constrained by the available budget for experimental payments. Second, as noted above, the aim of our design is to isolate the effect of sanctions within climate clubs. For this reason, we do not include explicit positive incentives. While incentive-based mechanisms are clearly relevant, introducing them would confound the identification of the specific role played by punishment. We have clarified this design choice and its scope in the revised manuscript. Third, the pledge stage is not

intended to assume that agents are intrinsically willing to cooperate. Rather, it is a standard experimental device to capture intentions and expectations prior to binding decisions, and to mimic the role of non-binding commitments in international climate negotiations (e.g., nationally determined contributions under the Paris Agreement). The experimental setup does not impose cooperation; subjects remain free to opt out or deviate, and the observed behavior reflects this. Finally, we agree that real-world participation in climate cooperation is limited and subject to substantial political constraints. Our experiment does not aim to reproduce these constraints directly, but to study behavior under controlled institutional conditions. We have clarified this distinction in the revised manuscript and moderated the interpretation of our results accordingly.

Competing Interests: No competing interests were disclosed.

Reviewer Report 24 January 2026

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Daniel Balsalobre-Lorente
University of Castilla-La Mancha, Ciudad Real, Spain

I consider that some more recent references should be included, along with a more extensive explanation of the methodology applied.
I recommend a minor revision.
For example, "We conducted controlled online experiments in which participants, representing countries with different endowments, decided whether to form voluntary coalitions that coordinated emissions reductions", should be explained and justified by the selection of countries.

Is the work clearly and accurately presented and does it engage with the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

Are all the source data and materials underlying the results available?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Applied Economics

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 24 Mar 2026

Alberto Antonioni

We thank the reviewer for these suggestions. We have addressed them in the revised manuscript, in particular by expanding the discussion of recent literature and providing a more detailed explanation of the experimental methodology. Most of these improvements have been implemented in response to the related concerns raised by Reviewer 2. In particular, we have extended the literature review to include more recent contributions on climate clubs, and clarified the rationale behind our experimental design choices. We have also revised the description of the experimental setup to better explain how participants represent countries with heterogeneous endowments and how this maps onto the research question. We believe these changes improve both the clarity of the methodology and the positioning of the paper within the current literature.

Competing Interests: No competing interests were disclosed.